

RELATIONSHIP BETWEEN WIND, WAVES AND RADAR BACKSCATTER

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I. INTRODUCTION

This report concerns our research conducted on Lake Washington in collaboration with S.P. Gogineni and R.K. Moore of the University of Kansas. The aim of the research was to investigate the relationship between wind, waves and radar backscatter from water surface. To this end, three field experiments with periods of 2 to 4 weeks were carried out during summer months in 1988, 1989 and 1990. For these periods, the University of Washington group provided (i) environmental parameters such as wind speed, wind stress and atmospheric stratification through measurements of surface fluxes (of momentum, sensible heat and latent heat) and of air and water temperatures; (ii) wave height spectra including both the dominant waves and the short gravity-capillary waves. Surface flux measurements were performed by using our well tested instruments: a K-Gill twin propeller-vane anemometer (Ataktürk and Katsaros, 1989) and a fast response thermocouple psychrometer. Wave heights were measured by a resistance wire wave gauge described by Ataktürk (1991) and Ataktürk and Katsaros (1987). The University of Kansas group was responsible for the operation of the microwave radars.

II. ACCOMPLISHMENTS UNDER THIS GRANT

The accomplishments and highlights of the experimental results are summarized below.

i. Surface Fluxes and Sea State:

Many attempts have been made to parameterize the surface fluxes in terms of routinely measured bulk quantities. A major difficulty in these attempts has been characterizations of the poorly known surface roughness parameters, z_0 , z_t and z_q for wind speed, sensible heat and water vapor, respectively (Blanc, 1985, 1987).

At our field site on Lake Washington we have the proper exposure for studying the surface fluxes of momentum, sensible heat and water vapor over pure wind waves at wind speeds of less than 10 m/s and a fetch of 7 km. Analyses of our Lake Washington data collected over the past few years show

that z_t and z_q do not vary with wind speed (stress) or sea state. Within the wind speed range of 3.5 to 8 m/s encountered in the field work, z_t and z_q are approximately constant. On the other hand, z_o depends on the sea state such that

$$\frac{gz_o}{u_*^2} \propto \left(\frac{u_*}{C_p} \right)^m ; m = 1$$

where C_p is phase speed of waves at the peak of the frequency spectrum, u_* is friction velocity and g is acceleration due to gravity. This result based on the atmospheric turbulence and wave measurements is consistent with other results obtained from field experiments (Merzi and Graf, 1985; Geernaert et al., 1987; Donelan, 1990; Smith et al., 1992).

We also devised a technique to estimate z_o from rms wave height and the equilibrium range parameter of the measured wave spectrum. For the cases of pure wind waves subject to unsteady wind speeds on Lake Washington, the technique provided better estimates of z_o hence, the neutral drag coefficient, than the atmospheric turbulent flux measurements. If the response of the waves to turning winds is included, the approach may have the potential to determine the momentum flux in frontal zones where the only direct method (i.e. eddy correlation technique) of measuring surface fluxes is no longer applicable due to lack of stationarity and horizontal homogeneity required by the similarity theory.

The results and relationships given above are analyzed in the Ph.D. dissertation by Ataktürk (1991) and were presented (Ataktürk and Katsaros, 1991) in *Air-Sea Fluxes and Water Waves Symposium, XX General Assembly of the IUGG, 11-24 August 1991, Vienna, Austria*.

ii. Wave Breaking Statistics:

By analyzing video films obtained simultaneously with our wind stress and wave height data, we also studied the incidence of breaking waves of three kinds: microscale, spilling and plunging types. Relationships were sought between various environmental parameters and the frequency of occurrence of each class of breaking.

Frequency of occurrence of microscale breaking was uniform in all the cases studied. However, those of spilling and plunging breakers showed a clear dependence on the wind stress and the evolutionary stage of the water waves hence, on the atmospheric turbulence intensity. Regression analysis indicated that percentage of crests with spilling and plunging breaking, $\%B_{s+p}$, could best be predicted by

$$\%B_{s+p} = 32.87 u_*^2 + 42.37 \frac{u_*}{C_p} - 2.47$$

with a correlation coefficient of 0.66 and standard error of 0.93.

Interpretation of the above relationship is straightforward. Since breaking results from excess wave energy, %B is expected to be larger for higher u_*^2 (i.e., wind stress). Also, for a given u_* , breaking is more frequent in a developing wave field (smaller C_p , larger u_*/C_p) than in a mature wave field (larger C_p , smaller u_*/C_p).

The wind input received by the waves is distributed among the wave components through non-linear wave-wave interactions. The temporal and spatial scales of this process are closely related to the characteristics of the wave field. Therefore, we hypothesize that the absolute width of the wave spectrum (or the value of the wavenumber at the peak of the spectrum) may be an important factor in wave breaking statistics. This subject requires further study.

We were also able to relate the variance of wave height in a certain frequency band, 6–10 Hz, with the wave breaking events. The visible evidence of breaking as spillers or plungers occurred for variances above a certain threshold. Therefore, wave height measurements provide an objective means of identifying wave breaking events.

The above findings of Katsaros and Ataktürk (1991) were presented in *IUTAM Symposium on Breaking Waves, 15–19 July 1991, Sydney, Australia*.

iii. Slicks – Effects on the Wave Spectrum:

The effects of surface slicks, man-made and natural, on different scales of waves in the spectrum were also studied with these data (Katsaros et al., 1989; Ataktürk, 1991). The results showed that surface slicks of either origin caused suppression of small scale waves in a similar manner. Waves with length of about 5 cm were found to be affected the most in accordance with the Marangoni theory. Influences on the dominant waves as observed occasionally were hypothesized to be due to combined effects of surface slicks and enhanced intermittency in atmospheric turbulence during conditions of stable atmospheric stratification.

iv. Radar Backscatter Studies:

In parallel with our hydrodynamic studies we collaborated with colleagues from the University of Kansas, Professors P. Gogineni and R. V. Moore, and their students. Simultaneous measurements of atmospheric turbulence, waves and radar backscatter power and range (at X and C bands in 1988 and 1989, and at Ka band in 1990) were conducted at our site on Lake Washington.

Preliminary processing of the 1989 and 1990 radar data by the University of Kansas group has been completed. The results include (i) time series of backscattered power, wave height and normalized radar cross section, (ii) power spectral densities of radar backscatter and wave height, and (iii) magnitude and phase of the modulation transfer function for various combinations of polarization, incidence angle and up/cross wind look angle (Salam et al., 1991).

The University of Kansas group also carried out a study of the sea spikes in the radar backscatter signal as a function of wind stress (Bush et al., 1991). Their results showed that while some of the sea spikes were associated with breaking waves or wedges (steep waves with no spilling), most of the sea spikes (about 75%) could not be attributed to any visible surface features.

On our part, analyses of the atmospheric environmental variables and surface waves corresponding to the periods of joint efforts were completed. Other plans for the current funding year include joint consideration of the available data sets to relate the radar backscatter signal to environmental variables, to compare statistics of breaking waves determined independently from radar backscatter and wave height measurements and, to investigate the modulation of short waves by the underlying long waves.

III. TECHNICAL REPORTS, PRESENTATIONS

One of the major accomplishments under grant NAGW-1322 to the University of Washington from the Ocean Processes Branch of National Aeronautics and Space Administration is the Ph.D. dissertation of Dr. S. S. Ataktürk (Ataktürk, 1991). Copies of this thesis were provided to NASA as a Technical Report.

The results from the above study were presented in *Air-Sea Fluxes and Water Waves Symposium, XX General Assembly of the IUGG, 11-24 August 1991, Vienna, Austria* (Ataktürk and Katsaros, 1991). Following this symposium, we participated in a workshop to review the state of knowledge of dependence of drag coefficient on wave properties. The workshop was concluded with a statement of where we are and what needs to be done on this subject (see Appendix A).

Our findings on the dependence of wave breaking statistics on wind stress and wave development were described in a manuscript by Katsaros and Ataktürk (1991). Copies of this manuscript were provided to NASA. (An additional copy is also enclosed with this report as a reference.)

The results from wave breaking study were presented in the *International Union of Theoretical and Applied Mechanics, IUTAM, Breaking Waves Symposium, 15-19 July 1991, Sydney, Australia*.

IV. REFERENCES

- Ataktürk, S.S., 1991: Characterization of roughness elements on a water surface. Ph.D. Dissertation, Department of Atmospheric Sciences, University of Washington, Seattle, WA, 98195, 196 pp.
- Ataktürk, S.S. and K.B. Katsaros, 1987: Intrinsic frequency spectra of short gravity-capillary waves obtained from temporal measurements of wave heights on a lake. *J. Geophys. Res.*, **92**, 5131-5141.
- Ataktürk, S.S. and K.B. Katsaros, 1989: The K-Gill: A twin propeller-vane anemometer for measurements of atmospheric turbulence. *J. Atmos. Ocean. Tech.*, **6**, 509-515.
- Ataktürk, S.S. and K.B. Katsaros, 1991: Characterization of roughness elements on a water surface. Presented in *XX General Assembly of the IUGG, 11-24 August, 1991, Vienna, Austria*.

- Blanc, T.V., 1985: Variation of bulk-derived surface flux, stability, and surface roughness results due to the use of different transfer coefficient schemes. *J. Phys. Oceanogr.*, **15**, 650–669.
- Blanc, T.V., 1987: Accuracy of bulk-method-determined flux, stability, and sea surface roughness. *J. Geophys. Res.*, **92**, 3867–3876.
- Bush, D.A., S.P. Gogineni, R.K. Moore, K.B. Katsaros, and S.S. Ataktürk, 1991: A video-aided study of sea spikes in radar backscatter at moderate incidence. (Manuscript submitted to *IEEE Trans.*)
- Donelan, M.A., 1990: *Air-sea interaction*. In *The Sea*, Vol. 9, B. Le Mehaute and D. Hanes, Eds., Wiley, New York, 239–292.
- Geernaert, G.L., S.E. Larsen, and F. Hansen, 1987: Measurements of wind stress, heat flux, and turbulence statistics over the North Sea during storm conditions. *J. Geophys. Res.*, **92**, 13127–13139.
- Katsaros, K.B. and S.S. Ataktürk, 1991: Dependence of wave breaking statistics on wind stress and wave development. Presented in *IUTAM Wave Breaking Symposium*, Sydney, Australia, July 15–19, 1991.
- Katsaros, K.B., H. Gucinski, S.S. Ataktürk, and R. Pincus, 1989: Effects of reduced surface tension on short waves at low wind speeds in a fresh water lake. In *Radar Scattering from Modulated Wind Waves*, G.J. Komen and W.A. Oost, Eds., Kluwer Academic Publishers, Norwell, MA, pp. 61–74.
- Liu, W.T., K.B. Katsaros, and J.A. Businger, 1979: Bulk parameterizations of air-sea exchanges of heat and water vapor including the molecular constraints at the interface. *J. Geophys. Res.*, **36**, 1722–1735.
- Merzi, N. and W.H. Graf, 1985: Evaluation of the drag coefficient considering the effects of mobility of the roughness elements. *Ann. Geophys.*, **3/4**, 473–478.
- Salam, A., D. Bush, S. Gogineni, and A. Zaide, 1991: Fundamental studies of radar scattering from water surfaces: The Lake Washington experiment. RSL Technical Report 7970–2. University of Kansas Center for Research, Inc. Lawrence, Kansas, 412 pp.
- Smith, S.D., R.J. Anderson, W.A. Oost, C. Kraan, N. Maat, J. DeCosmo, K.B. Katsaros, K.L. Davidson, K. Bumke, L. Hasse, and H.M. Chadwick, 1992: Sea surface wind stress and drag coefficients: The HEXOS results. *Bound.-Layer Meteorol.*, **60**, 109–142.

Appendix A:

FROM: Kristina B. Katsaros
TO: Prof. Yoshiaki Toba, Sendai, Japan
Prof. Ian F. Jones, Sydney, Australia

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Message: Ideas for the summary statement of Workshop on Surface Fluxes and Water Waves

Wind/wave research, in spite of dedicated efforts by numerous very talented scientists, is still in early stages of development. The physical–dynamic processes involved in wave growth are not sufficiently well understood that we can parameterize wave development in terms of a few parameters for most of the complex and transient situations where several wave trains exist simultaneously or the synoptic situation is not steady. However, progress has been made such that the simplest wind driven waves at moderate fetches (nearing full development) fit a consistent line on a plot of nondimensional roughness versus inverse wave age.

We also have identified candidate variables that are responsible for the large scatter on such plot for other field cases. We also have suggestions for why laboratory and field data do not seem to be relatable by a single fit on such a plot without reasonable scatter. Each category of experimental data are much better explained by individual fits of positive slope. The difference, we believe, is due to 1) the limited ability of the laboratory facilities to simulate atmospheric turbulence, secondary flows involving the whole planetary boundary layer and the turbulence in the water; and 2) variability of currents. In other words, the state of the fluid on both sides of the interface is important for surface wave development.

We therefore encourage experimenters to carefully include at least some measure of these additional parameters in future work. A list of the parameters needed for the air and water boundary layers and the wave field and, the parameters defining the context of the measurements are found in Table I.

The need to pursue simpler conclusive experiments for practical applications is abundantly clear in view of the remote sensing needs, for engineering purposes and for coupled atmosphere–ocean models.

Table I. Boundary Layer, Interfacial and Context Quantities to be Measured or Estimated for a Complete Wind–Wave Field Experiment

Near Surface, Local Parameters:

Symbols:

Turbulent fluctuations, mean wind velocity u', v', w', \bar{U} ,
and wind stress (at two or more heights, preferably) (τ, u_*)

Air temperature and humidity at known height, T_a, q ,
sea surface temperature, stratification parameter $T_s, z/L$

Directional wavenumber spectrum over all wavelengths . . $\Phi(\bar{k})$

Slope or significant slope of waves ak, ξ

Wave breaking, incidence, type

Surface currents and their turbulent fluctuations $\bar{u}_w, u_w', v_w', w_w'$

Context Parameters:

Fetch F

Duration T

Water depth or oceanic mixed layer depth D, Z_m

Height of atmospheric PBL Z_i

Secondary flow structures